

# Changes in Water Temperature of Backwaters During Fluctuating vs. Short-Term Steady Flows in the Colorado River, Grand Canyon

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**Abstract.** Discharge from Glen Canyon Dam, Arizona, fluctuates in a diel pattern which may affect native fishes and their habitats in the Colorado River, Grand Canyon. Differences in water temperature, turbidity, dissolved oxygen (DO) and pH in main channel and backwater habitats were compared between fluctuating and short-term (3-day) steady discharge regimes. Mean temperature in the main channel and backwaters displayed regular diel fluctuations, but mean temperatures were warmer under steady flows in both habitats ( $P < 0.01$ ). Mean main channel temperature was  $8.36^{\circ}\text{C}$  under fluctuating flows and increased to  $8.92^{\circ}\text{C}$  under steady flows. In backwaters, mean temperature increased from  $11.91^{\circ}\text{C}$  to  $14.18^{\circ}\text{C}$ , and minimum, maximum and diel temperature range were higher under steady flows ( $P < 0.01$ ). Mean and minimum DO decreased and range of DO increased ( $P \leq 0.03$ ), while mean, maximum and range of pH ( $P \leq 0.03$ ) increased in backwaters under steady flows. Mean turbidity did not significantly change ( $P \geq 0.35$ ). These water quality changes may affect native fish populations through their influence on primary and secondary production and the potential for a change in non-native fish community. These factors should be more closely examined before implementation of a steady flow regime, construction of a temperature control structure or other changes that might increase water temperature in the Colorado River in Grand Canyon.

**Key words:** temperature, dam discharge, fluctuating flow, steady flow, Colorado River, Glen Canyon Dam.

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## INTRODUCTION

The flow of water in the Colorado River through Grand Canyon is predominantly regulated by hypolimnetic discharge from Glen Canyon Dam. The closure of Glen Canyon Dam, in 1963, turned a seasonally warm, muddy river into one that is typically clear and constantly cold. This change has greatly affected the river corridor biota, particularly native fishes. Alteration of spawning and rearing habitat, blockage of migration and introduced non-native species have contributed to the extirpation of four of the original eight native species (Minckley 1991). Reproducing populations of only four native species remain: humpback chub, *Gila cypha* (listed as endangered; U. S. Fish and Wildlife Service 1990), flannelmouth sucker, *Catostomus latipinnis*, bluehead sucker, *Catostomus discobolus* and speckled dace, *Rhinichthys osculus*. As many as 17 exotic fish species, most of which are predators and/or competitors of native species, have been found within the Grand Canyon (Maddux et al. 1987, Valdez and Ryel 1995, Arizona Game and Fish Department 1996).

Glen Canyon Dam is operated as a peaking power hydropower facility. From 1963 through July 1991, daily discharge fluctuated widely, with no restrictions on ramping rates. During this period, discharge peaked as high as 893 m<sup>3</sup>/s (31,500 cfs) in the early afternoon, while discharge during the early morning could be as low as 28 m<sup>3</sup>/s (1,000 cfs) or 85 m<sup>3</sup>/s (3,000 cfs), depending on the time of year. On 1 August 1991, interim operations were implemented which restricted discharge to a maximum of 567 m<sup>3</sup>/s (20,000 cfs) and a minimum of 227 m<sup>3</sup>/s (8,000 cfs) from 07:00 to 15:00, and 142 m<sup>3</sup>/s (5,000 cfs) at night. Ramping rates were also restricted to 71 m<sup>3</sup>/s (2,500 cfs) per hour up and 43 m<sup>3</sup>/s (1,500 cfs) per hour down.

Changing from an unregulated to a regulated stream has caused backwaters to become increasingly important as rearing areas for native fishes in the Colorado River system (Holden 1978, Valdez and Clemmer 1982, Carter et al. 1985, Maddux et al. 1987, Arizona Game and Fish Department 1996). Backwaters, quiet pockets connected to the main channel (but with greatly reduced flow), are formed in areas of eddies where scouring occurs under higher flows. As water levels drop, a reattachment sand bar is exposed, partially isolating the eddy return channel and forming the backwater (Rubin et al. 1990). Not only do backwaters provide calm, sheltered water, they are also warmer and contain greater densities of aquatic invertebrates than the main channel (Cole and Kubly 1976, Arizona Game and Fish Department 1996). However, fluctuations in dam releases cause inundation and/or dewatering of backwaters, reducing their ability to support larval and juvenile fish (Kennedy 1979).

In an effort to improve habitat for native fish, a regimen of steady releases from Glen Canyon Dam has been proposed (U.S. Fish and Wildlife Service 1994). Stabilized river levels would prevent the daily loss and creation of backwaters. The present diel cycle of flow fluctuations forces juvenile fish to move into or out of many backwaters each day as these habitats are inundated and/or dewatered with changes in river stage. Jourdonnais and Hauer (1993) speculated that forced movement, caused by alterations in river discharge, may increase predation on juvenile fish. Eliminating fluctuations could improve conditions for juvenile fishes. It is likely that backwaters, under steady flow conditions, would support increased planktonic and benthic invertebrate communities as a result of increased temperature and decreased

daily flushing (Kennedy 1979). A dramatic increase in benthic invertebrate populations has been seen in backwaters sampled under reduced fluctuations (Arizona Game and Fish Department 1996) when compared to those sampled under flow regimes designed to maximize power production (Cole and Kubly 1976, Haury 1986, 1988). Conversely, turbidity, which is used as cover by native Colorado River fishes (Valdez and Ryel 1995, Arizona Game and Fish Department 1996), will likely decrease under steady flows. This would make backwaters and other near shore areas less hospitable to larval and juvenile native fishes. Additionally, other water quality parameters in backwaters, such as dissolved oxygen and pH will also be affected by steady flows and, subsequently, primary and secondary production.

This study was conducted to determine differences in diel temperature changes in backwaters and the main channel between fluctuating vs. steady flow regimes in the Colorado River, Grand Canyon. Herein, I provide initial data concerning the effect of steady flows on temperature, pH, dissolved oxygen and turbidity of backwater and main channel larval and juvenile native fish habitat. I also examine the effects that any changes might have on native fishes should a steady flow be implemented in the Colorado River, Grand Canyon, Arizona.

## STUDY AREA

This study was conducted on the Colorado River, in Grand Canyon National Park, near the confluence of the Colorado and Little Colorado (LCR) rivers (RK 99; RK = river kilometers in the Colorado River below Lees Ferry; Fig. 1). This reach was selected because of its importance to native fishes, as all four remaining native species reproduce in the LCR and rear in backwaters and the main channel of the Colorado River in this reach (Arizona Game and Fish Department 1996). The reach between Kwagunt Rapid (RK 90.1) and Lava Chuar Rapid (RK 105.4) was explored for suitable backwaters.

Four backwaters, RK 94.6L, 95.9L, 97.8L and 102.5R ('L' and 'R' denote side of river when facing downstream), were selected based on the likelihood that they would persist under fluctuating vs. steady flow regimes (Fig. 1). The backwaters varied in many physical characteristics which affect warming and water chemistry, including surface area, depth, mouth dimensions, amount of algae and/or aquatic vegetation and exposure to solar radiation.

## METHODS

My sampling period was four days of fluctuating flows (25-28 May 1994) and three days of steady flows (29 - 31 May 1994). Fluctuating flows ranged from 219.6-370.2 m<sup>3</sup>/s (7756-13075 cfs) while steady flows were approximately 236 m<sup>3</sup>/s (8,325 cfs). Steady releases from Glen Canyon Dam began at approximately 06:00 28 May 1994 and reached my backwater sites, at the confluence of the Colorado and Little Colorado rivers, at approximately 00:00 on 29 May 1994. Sampling was completed on 31 May 1994 when normal fluctuations resumed.

One temperature gauge (Ryan Tempmentor<sup>TM</sup>) was placed in the middle of each backwater on 24 May 1994. In one backwater (RK 97.8L) a HydroLab DataSonde

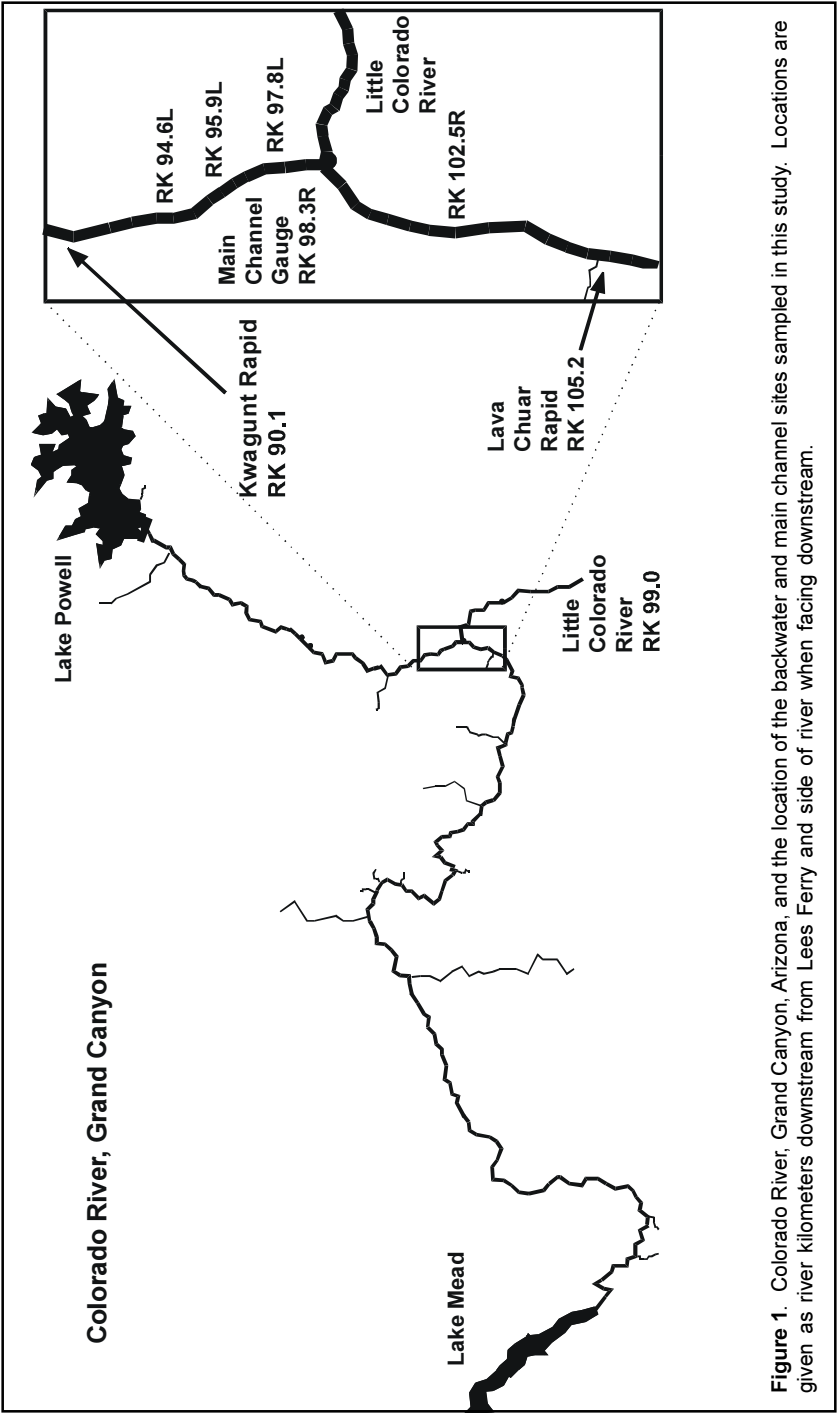


Figure 1. Colorado River, Grand Canyon, Arizona, and the location of the backwater and main channel sites sampled in this study. Locations are given as river kilometers downstream from Lees Ferry and side of river when facing downstream.

II<sup>TM</sup> was used which also recorded dissolved oxygen (DO) and pH. Each gauge was shaded from direct sunlight and suspended approximately 25 cm below the water surface. Turbidity was measured once each day in each backwater and the main channel using a Hach<sup>TM</sup> nephelometer. Main channel temperature and discharge data were obtained from the U.S. Geological Survey gauge on the Colorado River at RK 98.3R, above the mouth of the LCR. All instruments were set to record at 30 minute intervals from 25 May - 1 June 1994. Available direct solar radiation (hours) for each site at the end of May was later measured using a Solar Pathfinder<sup>TM</sup>. Differences in diel mean, minimum, maximum and range of temperature (°C), DO, pH and mean turbidity between steady vs. fluctuating river discharges in backwaters vs. the main channel were tested using a t-test. Probability was accepted when  $P \leq 0.05$ .

## RESULTS

### *Flows and Backwater Sites*

Two backwaters, RK 94.6 L and RK 97.8 L, were well established. They had been sampled regularly by Arizona Game and Fish Department (unpub. data) and contained aquatic, emergent and terrestrial vegetation in and around them. The remaining two backwaters, RK 95.9L and RK 102.5 R, were bounded by clean sand bars and were more ephemeral.

The backwater at RK 94.6 L was long (up to 61 m), wide (up to 7 m) and mostly shallow. Its size varied greatly with water elevation (Table 1). It also received the

**Table 1.** Representative and maximum depth (cm), surface area (m<sup>2</sup>) and hours of direct solar radiation in late May, for each backwater sampled, 25-31 May 1994, during fluctuating and steady flow regimes in the Colorado River, Grand Canyon, Arizona. Backwater location is given as river kilometer and side (left or right).

Parameter	Backwater Location			
	94.6L	95.9L	97.8L	102.5R
Representative Depth (cm)				
Fluctuating Flow	21-66	28-35	72-116	58-76
Steady Flow	64	52	73	54
Maximum Depth (cm)				
Fluctuating Flow	32-85	56-61	107-170	70-94
Steady Flow	124	81	112	70
Surface Area (m <sup>2</sup> )				
Fluctuating Flow	178-335	32-19	140-248	40-67
Steady Flow	324	57	165	145
Maximum Length (m)				
Fluctuating Flow	52-58	12-14	28-31	10-16
Steady Flow	61	19	34	18
Maximum Width (m)				
Fluctuating Flow	6-7	2	5-8	7-8
Steady Flow	6	6	5	10
Hours of Solar Radiation	7.25	5.5	6.75	4.75

greatest amount of direct solar radiation (7.25 hours from 09:00-16:15). Its mouth (connection with main channel) was wide and deep (>1 m) and its location and dimensions varied greatly with varying river stage. The foot (terminal end) of this site remains a backwater except under high discharges ( $510 \text{ m}^3/\text{s} = 18,000 \text{ cfs}$ ) not seen during this study, which would inundate the site. This backwater contained a dense mat of aquatic macrophytes, including *Potamogeton* and *Anacharis* with *Equisetum* and *Typha* along its sides.

The backwater at 95.9 L was very small (13 m), narrow (2 m) and shallow (Table 1). Its mouth was also shallow and narrow and the size of this backwater did not vary greatly with river elevation. This site would be inundated by flows barely exceeding those seen during this study. Due to its location, partially under an overhanging ledge, and the fact that the river there flows north to south, this backwater received little direct solar radiation (5.5 hours; 11:00-15:30). The only aquatic vegetation in this backwater was *Cladophora* that had drifted in from the main channel.

The backwater at RK 97.8 L was long (34 m) and wide (8 m) with both deep and shallow sections (Table 1). The mouth was wide, but very shallow. However, a boulder along one shore provided a site for scouring under high flows which created a deep hole. This site would also require flows exceeding  $510 \text{ m}^3/\text{s}$  for inundation. It was also very exposed to solar radiation (6.75 hours; 08:45-15:30) and contained much aquatic vegetation, including *Potamogeton* and *Equisetum* in the shallow areas and *Cladophora* in the deeper areas.

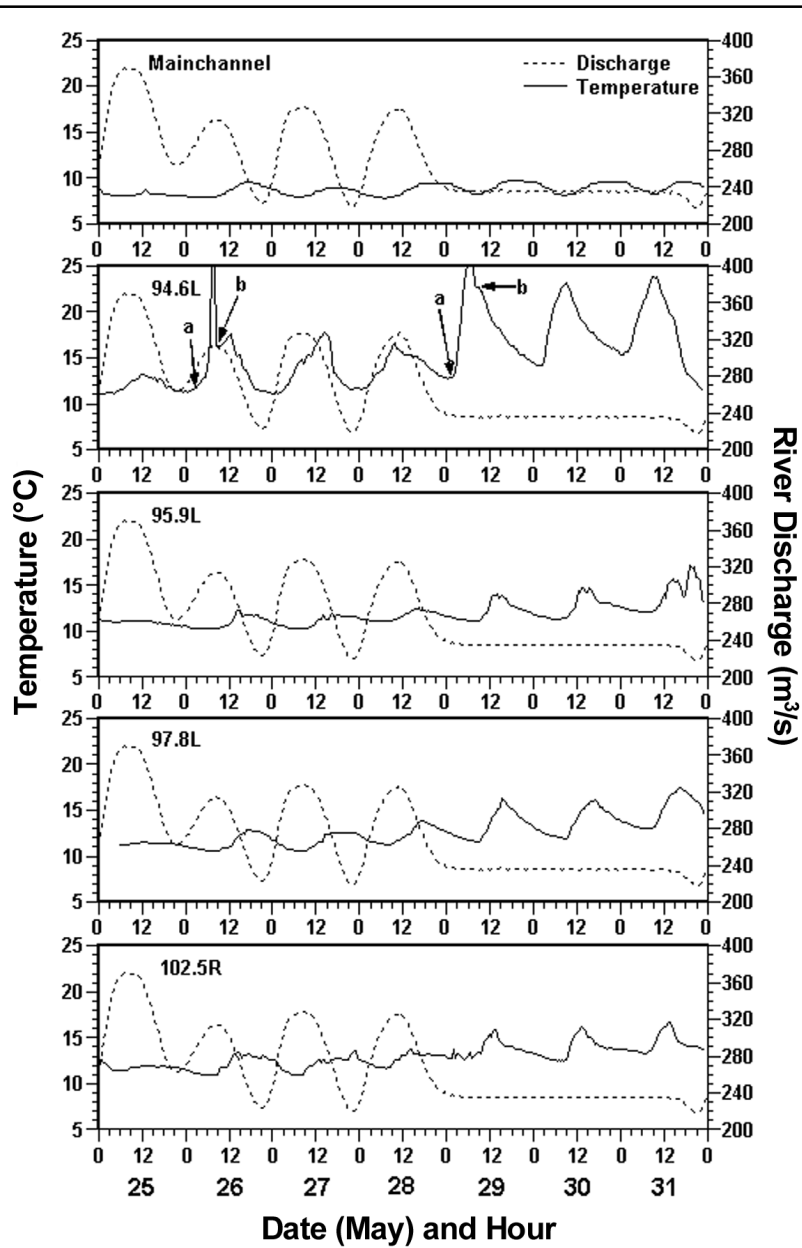
The backwater at RK 102.5 R was short (18 m), wide (10 m) and shallow with two arms and its mouth was wide and deep (Table 1). It was located in a narrow section of the canyon with Tapeats limestone walls that blocked much sunlight, resulting in only 4.75 hours of direct solar radiation each day (09:15-14:00). This backwater contained no aquatic vegetation except *Cladophora* that had drifted in.

### Temperature

Water temperatures in the main channel and backwaters displayed regular, diel fluctuations under fluctuating and steady flow regimes (Fig. 2). Maximum backwater temperatures occurred in midday (09:00-16:00, depending on the site) while the main channel was warmest around 18:00. Minimum backwater temperatures occurred near 06:00 for most sites, but around 00:00 for the backwater at 94.6L and in the main channel between 06:00-09:00.

In the main channel, mean temperature was  $8.4^\circ \text{C}$  under fluctuating flows but was significantly higher ( $P < 0.01$ ) at  $8.92^\circ \text{C}$  under steady flows (Table 2). Mean daily minimum temperature also significantly increased from  $7.8^\circ \text{C}$  to  $8.1^\circ \text{C}$ . Mean daily maximum and diel temperature range were not significantly different ( $P \geq 0.08$ ) between flow regimes in the main channel.

In backwaters, daily mean, minimum and maximum temperatures and diel temperature range were significantly greater under steady than fluctuating flows ( $P < 0.01$ ; Table 2). Daily mean temperature under fluctuating flows was  $11.9^\circ \text{C}$ , increasing to  $14.2^\circ \text{C}$  under steady flows. Mean daily minimum temperature increased from  $10.5^\circ \text{C}$  under fluctuating flows to  $11.5^\circ \text{C}$  under steady flows. Mean



**Figure 2.** Temperature changes, in main channel (RK 98.2) and backwaters (RK 94.6L, 95.9L, 97.8L and 102.5R), and river discharge during fluctuating and steady flows in the Colorado River, Grand Canyon, 25-31 May 1994. Temperature gauge in backwater at 94.6L was dewatered (a) and resubmerged (b).

**Table 2.** Mean, minimum and maximum temperature in the sampled backwaters and main channel during fluctuating and steady flows in the Colorado River, Grand Canyon, 25-31 May 1994.

Habitat/ Location	Fluctuating Flow				Steady Flow			
	Mean	Min	Max	Std Dev	Mean	Min	Max	Std Dev
Backwaters	11.9	10.1	17.7	1.2	14.2	10.9	23.8	2.2
94.6L	13.2	10.8	17.7	1.9	17.7	11.3	23.8	3.3
95.9L	11.0	10.1	12.5	0.6	12.7	10.9	17.0	1.4
97.8L	11.6	10.4	13.8	0.8	13.9	11.5	17.3	1.6
102.5R	12.0	10.8	13.7	0.7	13.9	12.3	16.6	1.0
Main Channel	8.4	7.6	9.4	0.5	8.9	8.0	9.6	0.5

daily maximum backwater temperature under steady flows was 18.7° C, but only 14.4° C under fluctuating flows. The mean diel temperature range was only 2.7° C under fluctuating flows, but increased to 5.6° C under steady flows.

In individual backwaters, daily mean and maximum water temperatures were significantly higher ( $P<0.05$ ) under steady flows in each backwater (Table 2). Daily minimum water temperature significantly increased ( $P<0.01$ ) at all sites, except RK 94.6L ( $P>0.07$ ).

### *Turbidity*

Mean turbidity decreased under steady flows, but not significantly ( $P\geq 0.35$ ). Mean main channel turbidity decreased from 6.936 to 2.681 Nephelometric Turbidity Units (NTU) under fluctuating and steady flows, respectively (Table 3). During fluctuating flows mean backwater turbidity was 9.396 NTU and decreased to 5.875 NTU under steady flows.

**Table 3.** Mean, minimum and maximum turbidity in the sampled backwaters and main channel during fluctuating and steady flows in the Colorado River, Grand Canyon, 25-31 May 1994.

Habitat/ Location	Fluctuating Flow				Steady Flow			
	Mean	Min	Max	Std Dev	Mean	Min	Max	Std Dev
Backwaters	9.4	1.6	31.3	5.3	5.9	1.2	11.4	2.1
94.6L	6.5	2.7	13.4	6.0	7.5	5.7	8.7	1.6
95.9L*	6.5	6.5	6.5	--	6.4	3.4	9.4	4.3
97.8L	6.1	1.6	10.0	4.2	2.1	1.2	3.0	0.9
102.5R	18.6	5.9	31.3	18.0	7.5	5.0	11.4	3.4
Main Channel	6.9	1.8	23.6	4.4	2.7	1.1	3.1	0.3

\* Turbidity was measured only once during fluctuating flows at this site.



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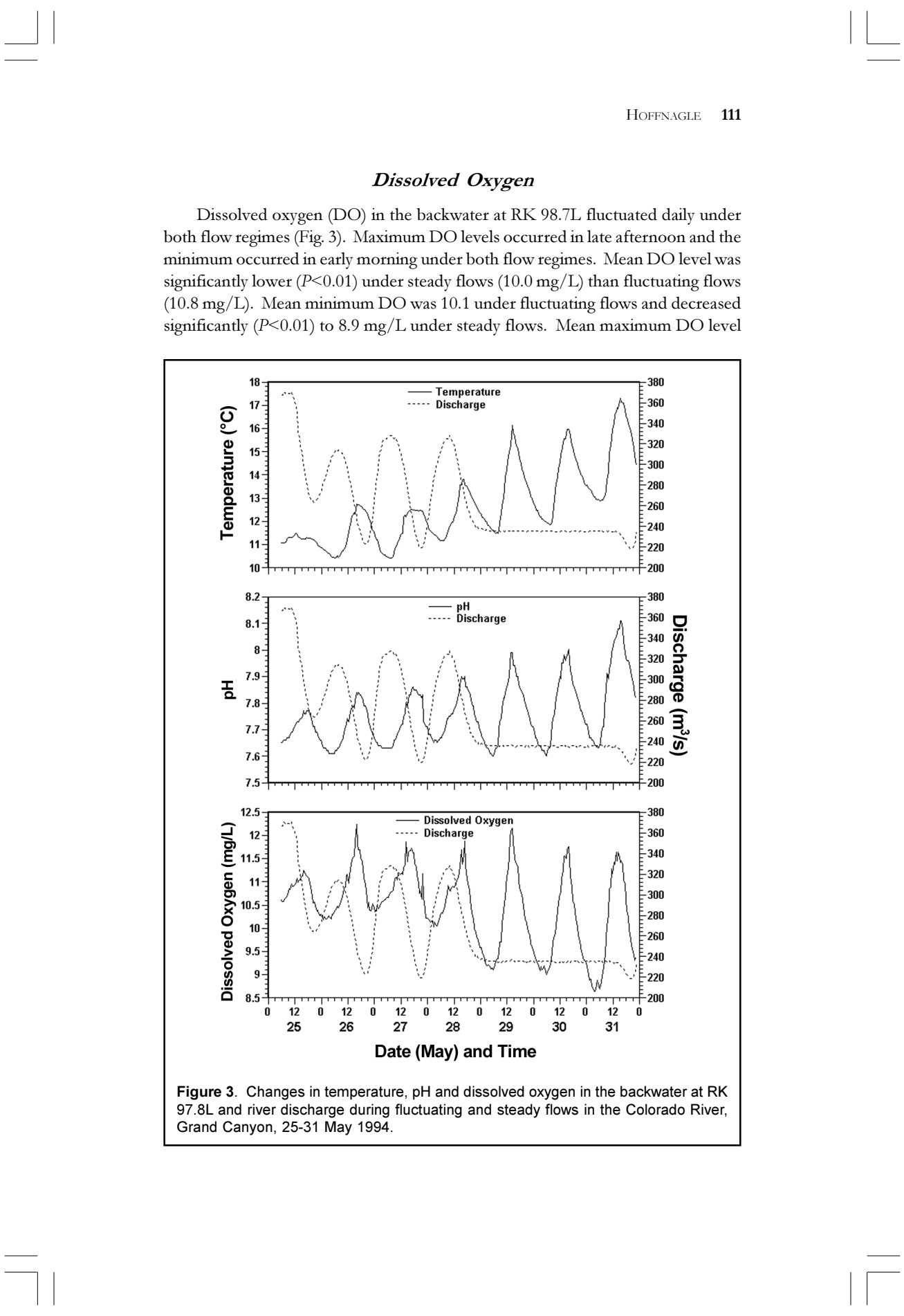
*Dissolved Oxygen*

Dissolved oxygen (DO) in the backwater at RK 98.7L fluctuated daily under both flow regimes (Fig. 3). Maximum DO levels occurred in late afternoon and the minimum occurred in early morning under both flow regimes. Mean DO level was significantly lower ( $P<0.01$ ) under steady flows (10.0 mg/L) than fluctuating flows (10.8 mg/L). Mean minimum DO was 10.1 under fluctuating flows and decreased significantly ( $P<0.01$ ) to 8.9 mg/L under steady flows. Mean maximum DO level

The figure consists of three vertically stacked panels sharing a common x-axis representing "Date (May) and Time". The x-axis has major ticks every 12 hours from May 25 to May 31.

- Top Panel:** Y-axis is "Temperature (°C)" ranging from 10 to 18. It shows a solid line for temperature and a dashed line for discharge. Temperature peaks around 16-17°C during the day and drops to about 11°C at night. Discharge shows significant fluctuations between approximately 220 and 360 m³/s.
- Middle Panel:** Y-axis is "pH" ranging from 7.5 to 8.2. It shows a solid line for pH and a dashed line for discharge. pH values generally range between 7.6 and 8.0, following a similar diurnal pattern to temperature. Discharge is shown as a dashed line.
- Bottom Panel:** Y-axis is "Dissolved Oxygen (mg/L)" ranging from 8.5 to 12.5. It shows a solid line for dissolved oxygen and a dashed line for discharge. DO levels peak at approximately 12 mg/L in the late afternoon and drop to a minimum of about 8.5 mg/L in the early morning. Discharge is shown as a dashed line.

**Figure 3.** Changes in temperature, pH and dissolved oxygen in the backwater at RK 97.8L and river discharge during fluctuating and steady flows in the Colorado River, Grand Canyon, 25-31 May 1994.

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*Dissolved Oxygen*

Dissolved oxygen (DO) in the backwater at RK 98.7L fluctuated daily under both flow regimes (Fig. 3). Maximum DO levels occurred in late afternoon and the minimum occurred in early morning under both flow regimes. Mean DO level was significantly lower ( $P<0.01$ ) under steady flows (10.0 mg/L) than fluctuating flows (10.8 mg/L). Mean minimum DO was 10.1 under fluctuating flows and decreased significantly ( $P<0.01$ ) to 8.9 mg/L under steady flows. Mean maximum DO level

The figure consists of three vertically stacked panels sharing a common x-axis representing 'Date (May) and Time' from May 25 to May 31, 1994. The x-axis has major ticks every 12 hours (labeled 0, 12, 0, 12, 0, 12, 0, 12, 0, 12, 0, 12, 0).

- Top Panel:** Plots Temperature (°C) on the left y-axis (range 10-18) and Discharge (m³/s) on the right y-axis (range 200-380). Temperature is shown as a solid line, and Discharge is shown as a dashed line.
- Middle Panel:** Plots pH on the left y-axis (range 7.5-8.2) and Discharge (m³/s) on the right y-axis (range 200-380). pH is shown as a solid line, and Discharge is shown as a dashed line.
- Bottom Panel:** Plots Dissolved Oxygen (mg/L) on the left y-axis (range 8.5-12.5) and Discharge (m³/s) on the right y-axis (range 200-380). Dissolved Oxygen is shown as a solid line, and Discharge is shown as a dashed line.

In all three panels, the discharge (dashed line) shows significant fluctuations, while temperature, pH, and dissolved oxygen (solid lines) show corresponding diurnal cycles. The dissolved oxygen levels are generally higher during periods of higher discharge.

**Figure 3.** Changes in temperature, pH and dissolved oxygen in the backwater at RK 97.8L and river discharge during fluctuating and steady flows in the Colorado River, Grand Canyon, 25-31 May 1994.

decreased from 11.90 mg/L under fluctuating to 11.86 mg/L under steady flows, but was not significantly different ( $P=0.92$ ). Diel DO range increased ( $P<0.05$ ) to 2.97 mg/L under steady flows, from that seen under fluctuating flows (1.79 mg/L).

### *pH*

pH levels showed regular diel variations in the backwater at RK 97.8L under fluctuating and steady flow regimes, with maximum pH occurring in the afternoon and minimum in early morning (Fig. 3). Mean, maximum, and diel range of pH were higher ( $P<0.05$ ) under steady than fluctuating flows, while mean minimum pH did not significantly change ( $P=0.15$ ). Mean pH increased from 7.72 to 7.80, while maximum pH increased from 7.9 under fluctuating flows, to 8.1 under steady flows. Diel range of pH also increased from 0.23 to 0.44. Minimum daily pH decreased from 7.63 to 7.61, but was not significantly different.

## DISCUSSION

It is evident that a 64-hour (three periods of daylight) regimen of steady flows caused changes in water quality parameters in the Colorado River main channel and backwaters. Temperature and pH increased, while DO and turbidity decreased. These changes and the potential for greater biotic and abiotic changes, under longer term steady flows, have important implications for native fishes in the Colorado River in Grand Canyon.

I found that the 3-day steady flow caused an increase in water temperature in backwaters and the main channel of the Colorado River during late May 1994. The full potential for backwater warming was probably not reached during this short period, and these data are insufficient to estimate the limit of warming or other water quality changes. The water did warm in both the backwaters and the main channel. It is, however, safe to say that temperatures would not have reached those of pre-dam conditions.

The amount of warming in the backwaters monitored in this study varied and was likely influenced by ambient temperature, physical location (accessibility to direct solar radiation), main channel temperature, the amount of water exchange between the backwater and main channel and backwater morphometry (size of mouth and surface area and volume of the backwater). Under fluctuating flows, backwaters may warm, but daily flushing with main channel river water resets backwater temperatures to approximately that of the main channel. Under the steady flow regime, diel fluctuations in temperature were still influenced by solar radiation and diel changes in ambient temperature but were less influenced by the main channel. With minimum temperatures well above that of the main channel and no surge of main channel water under the steady flow regime, backwaters held heat better than under fluctuating flows, allowing them to warm further the next day. In all sites, except RK 94.6L, the highest daily mean and minimum temperatures occurred on the last day of steady flows, and at all sites the highest maximum temperature occurred on the last day, indicating an increase of temperature over time, which would probably continue if the steady flows were of longer duration.

The diel cycle of flow fluctuations near the LCR is such that temperature variation in backwaters are maximized. During fluctuating flows, peak discharges reached the LCR gauge between 06:00 and 09:00, leaving the remainder of the day under steady or decreasing discharges. This permits backwaters in this area to warm considerably throughout the day due to little input of new, cold water from the main channel. In most other areas of the Colorado River in Grand Canyon warming should occur to a lesser degree since the timing of high and low discharge occurs at different times of the day. If low discharge occurs in the early to mid-morning, warming of backwaters should be greatly diminished as they will be continuously filled with cold river water during daylight hours.

Backwater temperatures that I recorded under fluctuating flows were not those preferred by native Grand Canyon fishes. Humpback chub prefer water temperatures of 21 - 24.4° C (Bulkley et al. 1982) and other native Colorado River fishes probably have similar preferences (Valdez and Ryel 1995, Arizona Game and Fish Department 1996). These preferred temperatures are far from the 7.6 - 9.6° C temperature range recorded in the main channel during this study under fluctuating and steady flows. Even in the monitored backwaters, maximum recorded temperature was 17.6° C under fluctuating flows. However, under the steady flow regime mean diel temperature in one backwater (RK 94.6L) reached 18.1° C, nearing the preferred temperature range for native fishes, and mean maximum temperature reached 23.8° C, well within the preferred range. Also, temperature in most backwaters showed indications of increasing with each day of steady flows. Therefore, it appears that under a regime of steady flows, temperature in backwaters will approach and may even exceed the preferred temperature range of native fishes. This is most likely to occur during warmer months, in shallow areas of backwaters and in lower reaches of the Colorado River in Grand Canyon.

Through warming of the water and reduced mixing with the main channel, steady discharges also affect other water quality properties of backwaters, such as dissolved oxygen, pH and turbidity. The Colorado River was extremely clear during the entire study and turbidity decreased in both backwaters and the main channel, but not significantly. Decreased turbidity may result in increased predation on larval and juvenile fish and main channel turbidity is probably already sufficiently low to affect fish behavior. Colorado River fishes evolved in a turbid system (Minckley 1991) and likely prefer turbid water. Arizona Game and Fish Department (1996) reported increased catches of juvenile humpback chub, flannelmouth sucker, speckled dace and fathead minnow under turbid conditions (>30 NTU). Valdez and Ryel (1995) reported increased catches of sub-adult and adult humpback chub in trammel nets at night and during periods of high turbidity (also >30 NTU) in the Colorado River. Sabo et al. (1991) found that high quality nursery ponds along the Mississippi River contained higher turbidity, dissolved oxygen and conductivity than low quality nursery areas.

As seen with temperature, DO and pH also varied with regular diel fluctuations under both flow regimes. Daily mean, minimum and/or maximum levels of these parameters changed under the steady flow regime due to increased photosynthetic/

respiratory activity by algae and macrophytes (Wetzel 1983). Under steady flows, daily maximum DO did not significantly vary between flow regimes. Dissolved oxygen was highest during the late afternoon when algal and macrophytic photosynthesis was greatest. Daily mean and minimum DO significantly decreased under steady flows with increases in water temperature and as biological oxygen demand during the night used  $O_2$  which was not replenished by the nightly influx of new water that occurs under fluctuating flows. However, DO levels recorded in these backwaters were never near 6 mg/L, below which fish growth and survival may be affected (Boyd 1979, Piper et al. 1982).

During the late afternoon, pH was also highest, probably due to the use of  $CO_2$  by algal and macrophytic photosynthesis (Wetzel 1983). Although pH increased significantly, the changes were small and it is unlikely that pH is limiting fish in this system, since fish generally do well in waters with a pH of 6.5 - 9.0 (Boyd 1979, Piper et al. 1982).

Therefore, it appears that fluctuations in river discharge also moderated the diel changes in DO and pH in this backwater caused by daily cycles of photosynthesis and respiration. However, as with changes in temperature, the limits of these changes under an extended period of steady flow cannot be predicted from these data.

These results show that backwaters and the main channel (to a lesser extent) will warm under a steady flow regime. Several biotic changes may be expected to be caused by this warming and subsequent changes, which may include alterations in algal, invertebrate and fish communities and the possibility of an increase in the distribution and prevalence of diseases and parasites. These changes in habitat and the biotic community are complex and may be beneficial or detrimental for native fish populations.

Algal and invertebrate communities in backwaters may change under steady flow conditions. It is likely that steady flows will cause an increase in backwater invertebrate densities in response to warmer temperatures and a lack of flushing. Increases in aquatic invertebrates under the current interim flow regime (small fluctuations) as compared to a peaking power flow regime (large fluctuations) have already been observed (Cole and Kubly 1976, Haury 1986, 1988, Arizona Game and Fish Department 1996). Steady flows and increased invertebrate densities would further improve backwaters as feeding areas for juvenile fishes. Although not examined in this study, the short duration of these flows was probably not long enough for significant changes to occur in populations of even those invertebrates with the shortest life cycles. Leibfried and Blinn (1987) reported an increase in total benthic standing crop (based on drift) in the main channel Colorado River under five months of steady flows, as compared to fluctuating flows. Warmer water and increased food abundance should cause an increase in fish growth and survival in all native fish. Lupher and Clarkson (1994) reared humpback chub larvae in 10°C, 14°C and 20°C water and found that length increased 10%, 37% and 83% and weight increased 28%, 195% and 951% over 30 days, in the respective groups. Similar, but less dramatic, results are expected in situ. However, it may be that increased use of backwaters by fish and subsequent changes in growth rates will not occur until invertebrate populations increase.

There are potential negative aspects to long periods of steady flows for native fishes. Main channel temperatures will increase, particularly in lower reaches of the river and may become hospitable to exotic warm and cool water predators and competitors already found in the Colorado River and/or the reservoirs immediately upstream (Lake Powell) and downstream (Lake Mead) from Grand Canyon, (Maddux et al. 1987, Valdez and Ryel 1995, Arizona Game and Fish Department 1996). These predators include striped bass, *Morone saxatilis*, walleye, *Stizostedion vitreum*, small-mouth bass, *Micropterus dolomieu*, and channel catfish, *Ictalurus punctatus*. Exotic competitors include fathead minnow, *Pimephales promelas*, which is already common, plains killifish, *Fundulus zebrinus*, and red shiner, *Cyprinella lutrensis*, which are becoming increasingly common, and green sunfish, *Lepomis cyanellus*, presently found in low numbers within the system. Additionally, Blinn et al. (1989) found that epiphytic diatom communities from the Glen Canyon Dam tailwaters changed from large, upright forms to smaller, closely adnate forms with an increase in water temperature from 12°C to 18°C. Adnate forms of diatoms may be more difficult for grazing fish to consume.

It is possible that backwater temperatures may rise too high during the late afternoon, making these areas unsuitable for juvenile fishes, particularly in the lower reaches of the Grand Canyon. Maximum backwater temperatures recorded under the current discharge regime of modified fluctuations reached as high as 26.6° C in May (Arizona Game and Fish Department 1996). It is also possible that increased algae, phytoplankton and macrophyte growth may make backwaters anoxic during darkness, further reducing their suitability to fish. This has been observed in the backwater at RK 88.86 (Arizona Game and Fish Department 1996).

Increased temperature may also allow the invasion of new parasites and diseases. Fifteen species of parasites have been found in the lower LCR (Clarkson et al. 1997, Brouder and Hoffnagle 1997, Hoffnagle et al. 2000). Increased mainstem temperatures may allow these parasites to expand their distributions within Grand Canyon. *Bothriocephalus acheilognathi*, the Asian fish tapeworm, is a thermophilic parasite of planktivorous cyprinid and cyprinodontid fishes and has been known to cause high mortality rates in fish (Hoffman and Schubert 1984). Cold temperatures in the mainstem Colorado River presently appear to keep this parasite from being able to complete its life cycle in the Colorado River in Grand Canyon. In the LCR, it infects humpback chub, speckled dace, plains killifish, common carp, red shiner and fathead minnow (Clarkson et al. 1997, Hoffnagle et al. 2000). The maximum temperature recorded in this study was 23.8°C and maximum daily mean temperature was 18.07°C, very close to the 20°C needed by this parasite to complete its life cycle (Granath and Esch 1983). Brouder and Hoffnagle (1997) examined the distribution of *B. acheilognathi* in humpback chub, speckled dace, fathead minnow and plains killifish throughout the Grand Canyon in 1994 - 1995 and found infected fish to be most common in and near the LCR. However, an infected speckled dace was found in the main channel Colorado River as far as 214 km downstream and in the mouth of Kanab Creek (132 km downstream). Hoffnagle and Landye (1999) reported the captured of speckled dace infected by *B. acheilognathi* in Kanab Creek in 1998. Increas-

ing Colorado River water temperatures to those preferred by humpback chub will likely increase the infection rate by *B. accheilognathi* in all susceptible fish. That, coupled with the continual displacement of fish downstream, will facilitate the invasion of *B. accheilognathi* into other tributaries and possibly the main channel. Increased infection of humpback chub by *B. accheilognathi* could threaten this endangered fish. Other parasites found in the LCR may be more dangerous to humpback chub, including some that may alter the behavior of their hosts (Hoffnagle et al. 2000).

My results clearly demonstrate that water temperature will increase under a regime of steady flows during periods of warm weather. Additionally, dissolved oxygen and pH will be affected by this flow regime and turbidity changes may also be expected under longer-term steady flows. The effects of steady flows and changing river and backwater conditions on plankton, aquatic invertebrates and fishes were not tested but could be considerable. Therefore, it is apparent that further study is needed to assess the potential changes of long-term steady flows on larval and juvenile native fishes, their food sources, parasites and habitat before such changes are made. These studies, both laboratory and in situ, should provide significant information on the utility of steady releases for management of native fish populations in the Colorado River, Grand Canyon.

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